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Short communication

A new strategy for reusing the oilfield-produced water as boiler feedwater without desilication

Ying Xu[a], Danni Shen[b], Bin Dong[a,*], Xiaohu Dai[a]

[a] *State Key Laboratory of Pollution Control and Resource Reuse, School of Environmental Science and Engineering, Tongji University, Shanghai 200092, China*
[b] *Shanghai Textile Energy Saving Environmental Protection Center, Shanghai 200082, China*

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ABSTRACT

One of key challenges for reusing oilfield-produced water as boiler feedwater was desilication, which can produce large amounts of silica sludge and concentrated solutions causing serious secondary pollution. In this paper, an environmentally friendly method that oilfield-produced water is treated by advanced softening without desilication (AS) was conducted *via* a lab-scale test. Experimental results showed that average scaling rate of the AS was only 0.0018 g/l, which was only a third of that of traditional desilication (0.0056 g/l). Si content in scales formed by AS was less than that of traditional desilication, indicating that softening is more effective than desilication in controlling silicate scales. These suggested that more free silicates and silica can be taken away as volatile by saturated steam under the conditions of 285 °C and 7 MPa. However, these findings can offer an important reference for reusing the oilfield-produced water without desilication into boiler.

1. Introduction

Large volumes of produced water have been produced in Chinese oilfields. The daily global production of produced water is 250 million barrels, which is three times the amount of oil produced [1,2]. The produced water was environmentally hazardous and difficult to be treated due to containing a complex mixture of organic compounds, anions, cations, dissolved solids, and suspended solids [3–5]. Therefore, how to dispose the vast oilfield-produced water has been an urgent and stubborn problem. From ecological, environmental and economic standpoints, the most effective disposal method is to reuse into the steam injection-boiler in oilfields [6,7].

However, one of the key challenges for reusing the produced water is silicate scaling, which is detrimental to the thermal efficiency and security of the steam injection-boiler [8]. Many techniques are used to remove silica from oilfield-produced water [9,10], but most of the methods can produce large amounts of silica sludge and concentrated solutions, causing serious secondary pollution. Additionally, these methods remain expensive. In China, desilication costs account for more than half of the total operating cost of oilfields. Is there a method that can be instead of desilication? Based on the basic scaling mechanism that hardness cations (Ca, Mg and Fe ions) react with anions (such as silicate radical, carbonate radical, and sulfate radical) to form insoluble compound, our teams have put forward a new idea that the advanced softening (total hardness is less than 30 ug/l, calculated with $CaCO_3$) replaces desilication for treating the oilfield-produced water.

In this study, the advanced-softened, silica-rich, oilfield-produced water (ASOW) and general-softened, desilication, oilfield-produced water (GDOW) which is the traditional way of disposal were used as boiler feedwater in lab-scale tests, respectively. Meanwhile, the total hardness, silicon content, and Fe element in the two kinds of oilfield-produced water were monitored. Scanning electron microscope-energy dispersive spectrometer (SEM-EDS), inductively coupled plasma-mass spectroscopy (ICP-MS) and X-ray diffraction (XRD) were applied to composition analyses of scales. Scaling rates of different water quality were determined by weighing the mass of scale obtained. The positive results can offer an important reference for reusing the oilfield-produced water without desilication as steam-injection boiler feedwater.

2. Experimental

2.1. Experimental system

The figures of reactor system (5KCF-10, Shuguang Plant) in the lab-scale test are shown in Fig. 1, which was used to simulate the stream-injection boiler. Two new coiled tubes, which were preprocessed with impeller blasting, were connected to the test boiler serving as scaling surface in the test (Fig. 1(b)). In addition, the new coiled tubes were made of 15CrMo alloy steel. The

* Corresponding author. Fax: +86 21 65983602.
E-mail addresses: assassinxu@sina.cn (Y. Xu), tj_dongbin@163.com (B. Dong).

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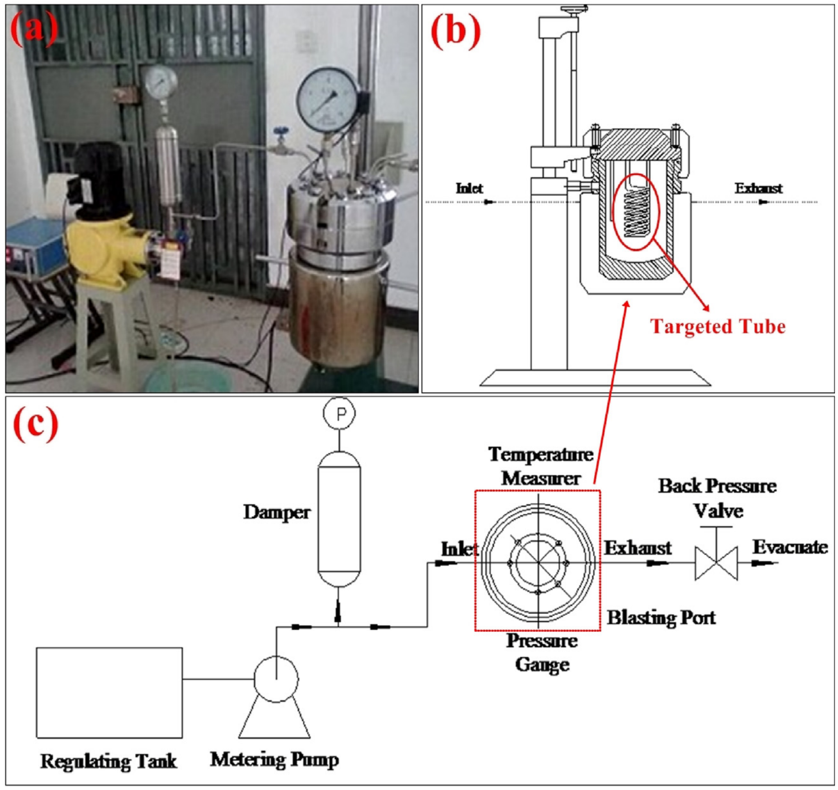

Fig. 1. Figures of the lab-scale test reactor system: (a) picture of the reactor, (b) structure diagram of the reactor, (c) structure diagram of reactor system.

temperature and pressure in the reactor were 285 °C and 7 MPa, respectively, which are in accordance with the parameters of steam-injection boiler in industrial production of the oilfield.

2.2. Sample preprocessing and analysis methods

Each of the tests (named AS and GD tests) was carried out at 1.2 l/h for 168 h, and the feedwaters were coming from the ASOW and GDOW, respectively. At the end of the tests, the targeted tubes were taken away. Then, scales were collected and weighed (m_{AS} and m_{GD}), and the average scaling rates can be calculated by the following formula (Eq. (1)). The tests have been repeated to avoid sampling uncertainty.

$$\upsilon_{Scaling\ rate}(\text{g/l}) = \frac{m_{Scales}}{V_{Feedwater}} \quad (1)$$

In addition, all of the solid samples (AS and GD samples) were divided into two parts. One part was reserved and the other part was ground into a powder that could pass through the griddle at the 0.075 mm pore rating by agate mortar. Parts of the powder samples (0.2000 g ± 0.0005 g) were digested with microwave-assisted [11,12]. Elemental composition and compound of the powder samples were determined by using SEM-EDS (Hitachi S-4800), ICP-MS and XRD (Bruker D8 Advance). Besides, the composition analysis measurements of every sample were performed in duplicate and the results show the mean of duplicate samples in this study.

3. Results and discussion

3.1. Softened water chemistry

The average values and the numerical range of the raw water quality parameters in the lab-scale test were summarized in the Supplementary Material (Tables S1–S3). Table 1 provides basic parameters of ASOW and GDOW. It shows that the ratio of silicon content and total hardness was 10,844 in the ASOW, however, only 700 in the GDOW, indicating that lots of free silicates, amorphous silicon, and silica are in the ASOW due to trace metal ions (Ca, Mg, and Fe ions). According to the results, it can be inferred that more chance for silicon to be transformed into gaseous in the ASOW.

Table 1
The basic parameters of ASOW and GDOW (mg/l, 25 °C).

	GDOW		ASOW	
	AV	SD	AV	SD
Silicon content (SiO_2)	75.6	± 9.973	271.1	± 17.92
Total hardness ($CaCO_3$)	0.108	± 0.0211	0.025	± 0.0077
Ca	0.085	± 0.0068	0.018	± 0.0075
Mg	0.013	± 0.0018	0.004	± 0.0011
Fe	0.140	± 0.0320	0.009	± 0.0023

a AV = average values; a SD = standard deviation.

Table 2
Average scaling rates (ASR) of the GD and AS tests.

		m_{scale} (g)	$V_{feewater}$ (l)	ASR (g/l)	AV	SD
GD	1	0.9635	202.0	0.0048	0.0056	± 0.0008
	2	1.2603	200.8	0.0063		
	3	1.1814	201.3	0.0059		
AS	1	0.4025	202.2	0.0020	0.0018	± 0.0002
	2	0.3685	201.6	0.0018		
	3	0.3168	202.1	0.0016		

a AV = average values; a SD = standard deviation.

3.2. Mass of the scales

The average scaling rates (ASR) of the GD and AS tests were calculated and presented in Table 2. Fig. 2 provides the images of scales formed by different kinds of feedwater after tests. Notice-